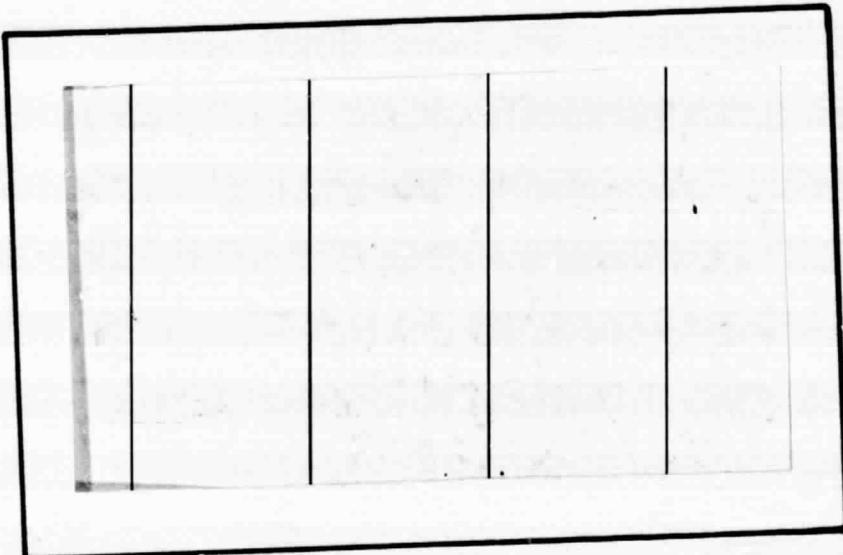


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REPUBLIC COMPANY



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SPACE SHUTTLE GALLEY
WATER SYSTEM
TEST PROGRAM

FAIRCHILD

Fairchild Republic Company Farmingdale, L.I. New York 11735

For Submittal to
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Johnson Spacecraft Center
Houston, Texas 77058

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1.0 SUMMARY

A water system for food rehydration was tested to determine the requirements for a Space Shuttle Galley flight system. A new food package concept had been previously developed in which water is introduced into the sealed package by means of a needle and septum. The needle configuration was developed and the flow characteristics measured. The interface between the food package and the water system, oven, and food tray was determined.

2.0 INTRODUCTION

Fairchild Republic Company with the Pillsbury Company had in prior studies (NAS 9-13138) developed the Shuttle food management system utilizing dehydrated (freeze dried) food as the primary food. A new food package was developed in which the food is vacuum packed in a lightweight laminated plastic wrap. Rehydration water is introduced into the package by bonding an elastomeric septum to a portion of the wrap and inserting a hypodermic-like needle through the septum. This current program was undertaken to test and demonstrate the concept and to define the requirements for the Galley water system. Food packages for test were prepared by The Pillsbury Company. Fairchild fabricated test equipment and performed the rehydration tests.

3.0 SCOPE

The test program was designed to verify the successful interfacing between the food package and the needle probe. The quality of the rehydration in terms of free water, dry spots, and temperature was assessed. The requirements for the galley water system were determined. Only the functional aspects of the rehydration system were investigated. The requirements of a flight system in terms of weight, volume, and quality were not investigated.

4.0 TEST OBJECTIVES

4.1 Measure Food Package Internal Air Pressure During Storage

The achievable vacuum in the food package will be measured to determine its effect on the quality of rehydration.

4.2 Measure Septum Characteristics

The septum dimensional variations in the manufactured package will be measured to determine requirements for needle length and stroke. The alignment of the needle and septum will be determined.

4.3 Septum and Septum/Food Mass Resistance to Needle Penetration

The forces required to insert and withdraw the needle will be measured so that the package restraint and insertion mechanism requirements can be defined.

4.4 Septum Sealing Ability

Air in-leakage during rehydration and water out-leakage following needle withdrawal will be measured so that the septum thickness requirements can be defined.

4.5 Water Flow Characteristics

The pressure drop in the needle probe will be measured at rated flow. The load pressure created by the food mass will be measured.

4.6 Quality of Rehydration

The completeness of rehydration, uniformity, presence of dry spots, or water accumulation will be determined to assess the relationship or impact on the water system in terms of flow rate and required quantity.

4.7 Interface With Galley

The food package variations that may affect the interfacing of the package with the water system, tray inserts, and the oven will be determined. The handling characteristics of the rehydrated food will be determined.

5.0 TEST EQUIPMENT AND PROCEDURES

5.1 Needle Design

Three needle configurations shown in Figure 1 were used in the testing program. The needles were modified standard hypodermic syringe needles with "Luer" lock fitting. Gauge number 15 was chosen as the smallest bore that provides a one pound per minute flow at the water pressure available on Shuttle. The configurations are:

- a) A standard needle shortened to about 0.03 m (1.2 inches).
- b) A standard needle fitted with a stainless steel plug at the tip. The needle wedge-shaped point is re-ground. Two apertures are formed by drilling a radial hole, equal to the needle bore, at a distance of 0.01m (0.4 inch) behind the tip.
- c) A plugged needle as in b) but the point ground axially symmetric.

5.2 Water System

The water system for rehydrating food packages and measuring flow characteristics is illustrated schematically in Figure 2. Line pressure is controlled by the regulated pressure gas supply. Water at the desired temperature is stored in a graduated cylinder reservoir. For hot water the cylinder is surrounded by a coaxial heater to maintain temperature. Flow rate is measured by timing the delivery of a given quantity of water. Just upstream of the needle a pressure gauge gives the needle inlet pressure. The needle is attached to a holder consisting of a modified standard syringe with "Luer" lock tip, a connector to the water supply and a support rod. The support rod is mounted in bearings and moves the needle axially with an adjustable stroke. The food package on the septum sample holder is supported on the same platform with the septum lined up with the needle point. The platform can be rotated 180 degrees so that the needle can be pointing straight up through straight down.

5.3 Package Internal Air

The internal air in the sealed food package can be determined by lowering the pressure of the surrounding air below that in the package. The resulting differential pressure forcing the food wrapper outward can generate an easily measured force against a face of the package. More simply the external air pressure at which the

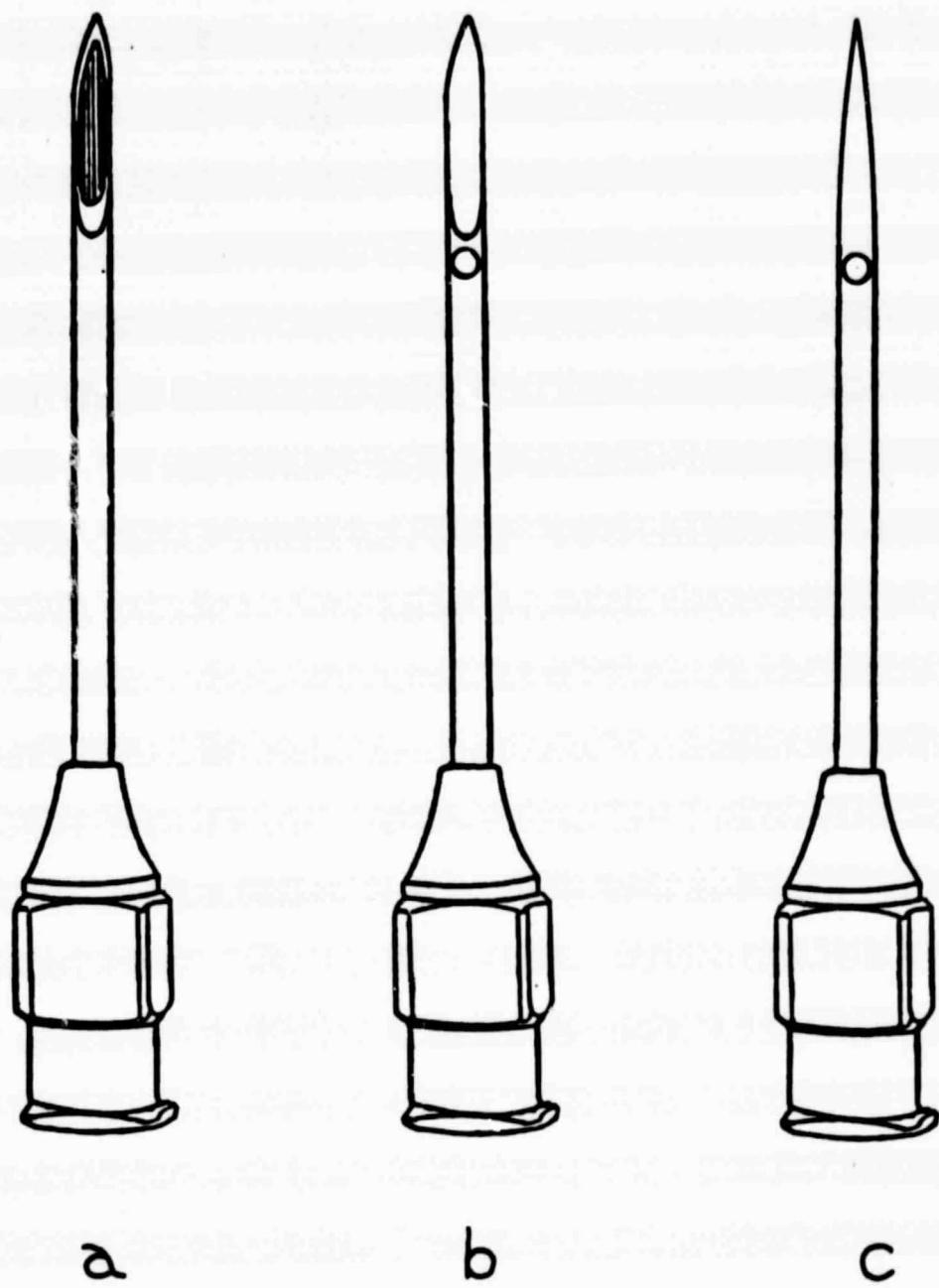


Figure 1. Rehydration Needle Types

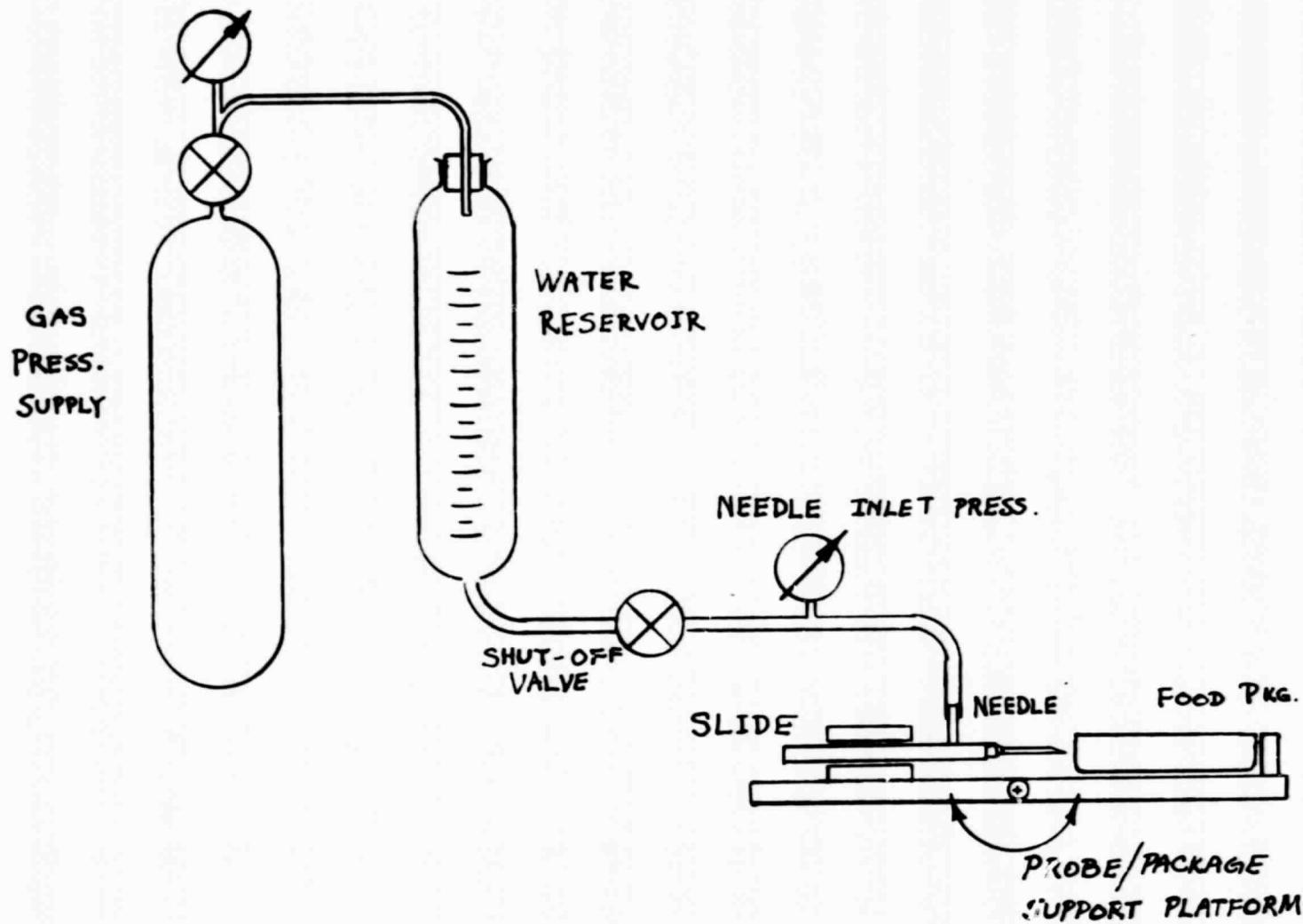


Figure 2. Water System Schematic

wrapper is observed to just raise from the food surface can be taken as approximately the food package internal air pressure. The latter approach, pictured in Figure 3, is quite satisfactory and relatively fast.

The food package to be tested is placed in a glass vacuum bell jar and the chamber is pumped down slowly. The surface of the food package is closely observed and the chamber pressure at which the wrapping lifts off the food is recorded. Reversing this procedure by letting air back into the chamber provides a check. The measurement is estimated to be accurate within about 667 Newton/m^2 (5mm Hg) which is sufficient compared to that quantity of air that might present a problem for good rehydration.

5.4 Septum Sealing Test

5.4.1 Air In-Leakage

This test is concerned with the measurement of air into the evacuated food package during the insertion of the needle probe. Figure 4 pictures the food package rehydration apparatus which has been converted to leak check an isolated sample of food package wrapper with septum material. The test specimen, about 0.025m (1 inch) in diameter is mounted on a removable flange at the end of a pipe. The other end of the pipe is fitted with a vacuum valve and connected to a mechanical pump. The total evacuated volume is $2 \times 10^{-4} \text{ m}^3$ (12.2 in²) which is about the same as the average food package. A pressure tap to an absolute pressure gauge shows the pipe internal pressure.

For the test the pipe is evacuated and valved off. The internal pressure is monitored for a minute to establish that no leak exists. A test needle, which has been plugged to prevent leakage through the needle is placed in the needle holder. The needle is pushed through the septum and for a period of 30 seconds the pipe pressure is monitored. This time is comparable to the average fill time, but the test is more severe than the actual case since a one atmosphere pressure differential is maintained throughout the test. In an actual filling, the pressure differential decreases continuously as water enters the package.

5.4.2 Water Out-Leakage

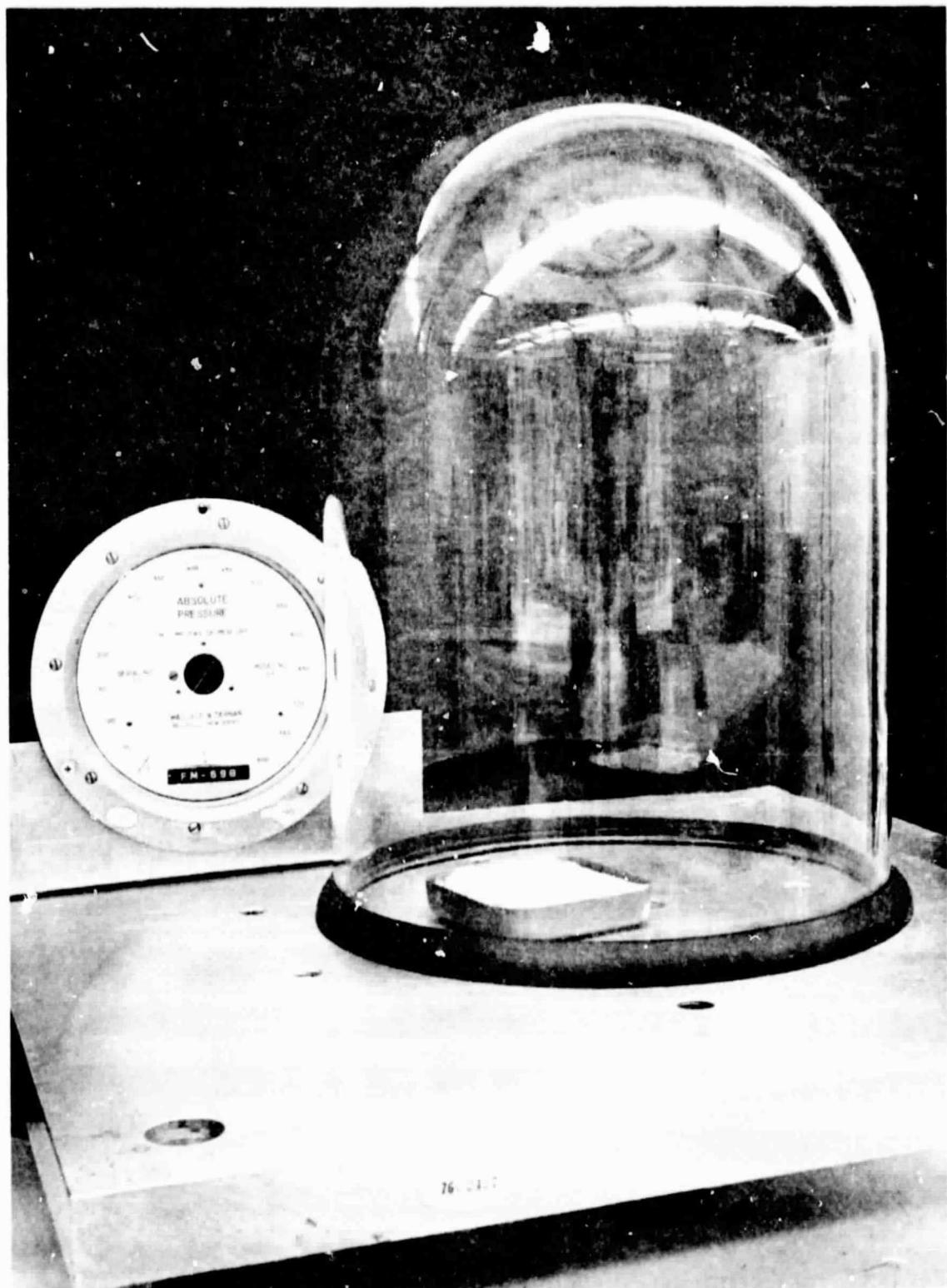


Figure 3. Food Package Internal Air Measurement

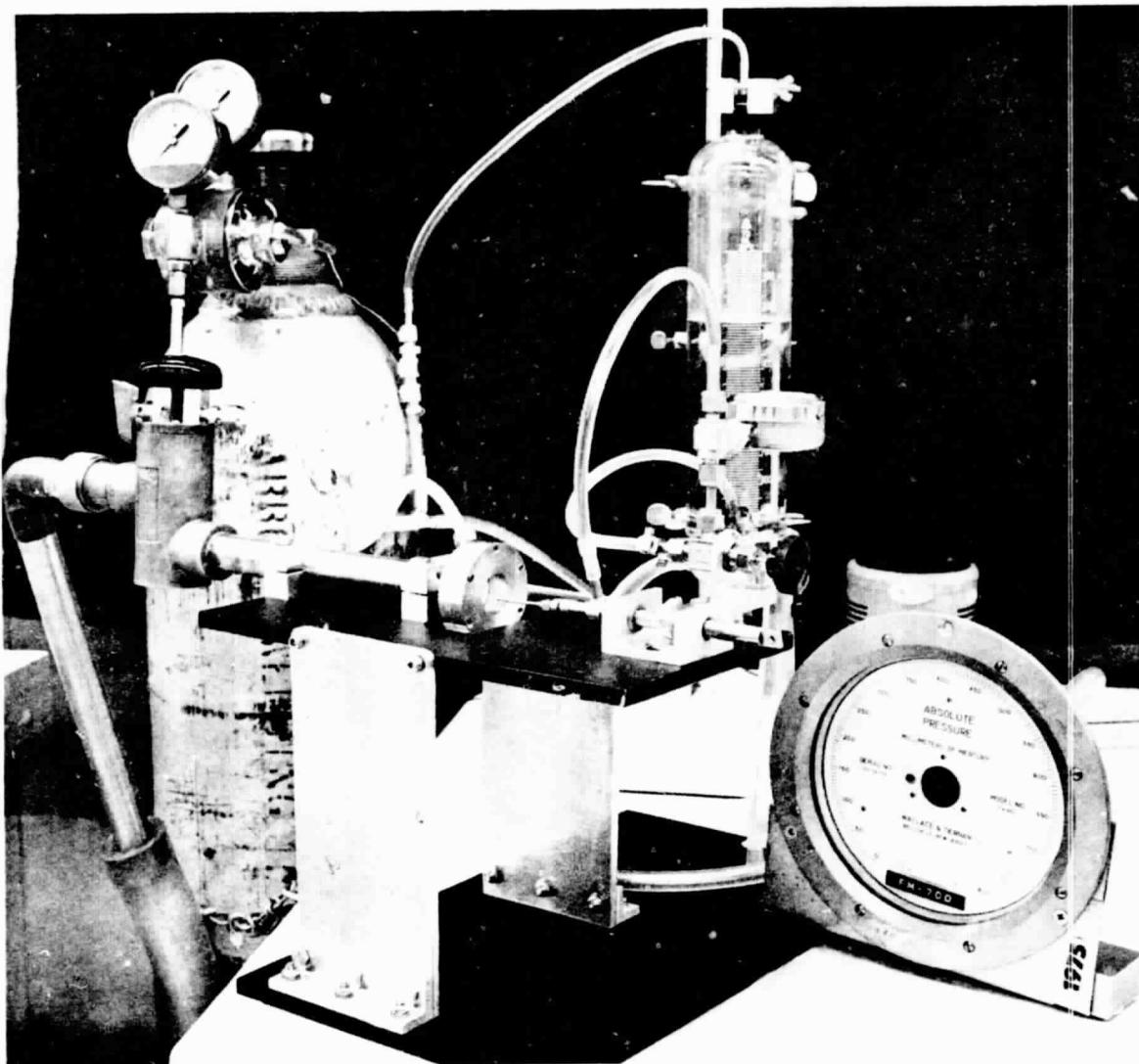


Figure 4. Septum Air In-Leakage Test

5.4.2.1 Isolated Septum Specimen

The apparatus used in the air leakage test is modified as shown in Figure 5 to measure water leakage through the septum after the needle is withdrawn. The support platform has been tilted 90 degrees so that the pipe is now vertical with the septum specimen at the bottom and the needle pointing upwards. The lower portion of the photograph is a reflection which gives a better view of the septum.

The septum is covered with a layer of water, the valve is closed, and the pressure tap is connected to the regulated pressure gas supply. After puncturing the septum and withdrawing the needle, the gas pressure is slowly increased and the septum surface is observed for signs of leakage.

5.4.2.2 Food Package Samples

Food packages are rehydrated with the rehydration apparatus. Observations are made of the septum while the package is subjected to handling loads that are at least equivalent to the greatest loads conceivably encountered during the normal food preparation cycle.

5.5 Septum Resistance

The septum resistance to needle insertion and withdrawal is measured with the rehydration apparatus as shown in Figure 6. A force gauge is used to push the needle through the septum, and the highest force is recorded. The apparatus friction is negligible. For withdrawal the tension end of the gauge is hooked to the needle holder and the highest measured force as the needle is withdrawn is recorded. The septum specimen apparatus (Figure 4, ref.) is also used for better control of septum thickness.

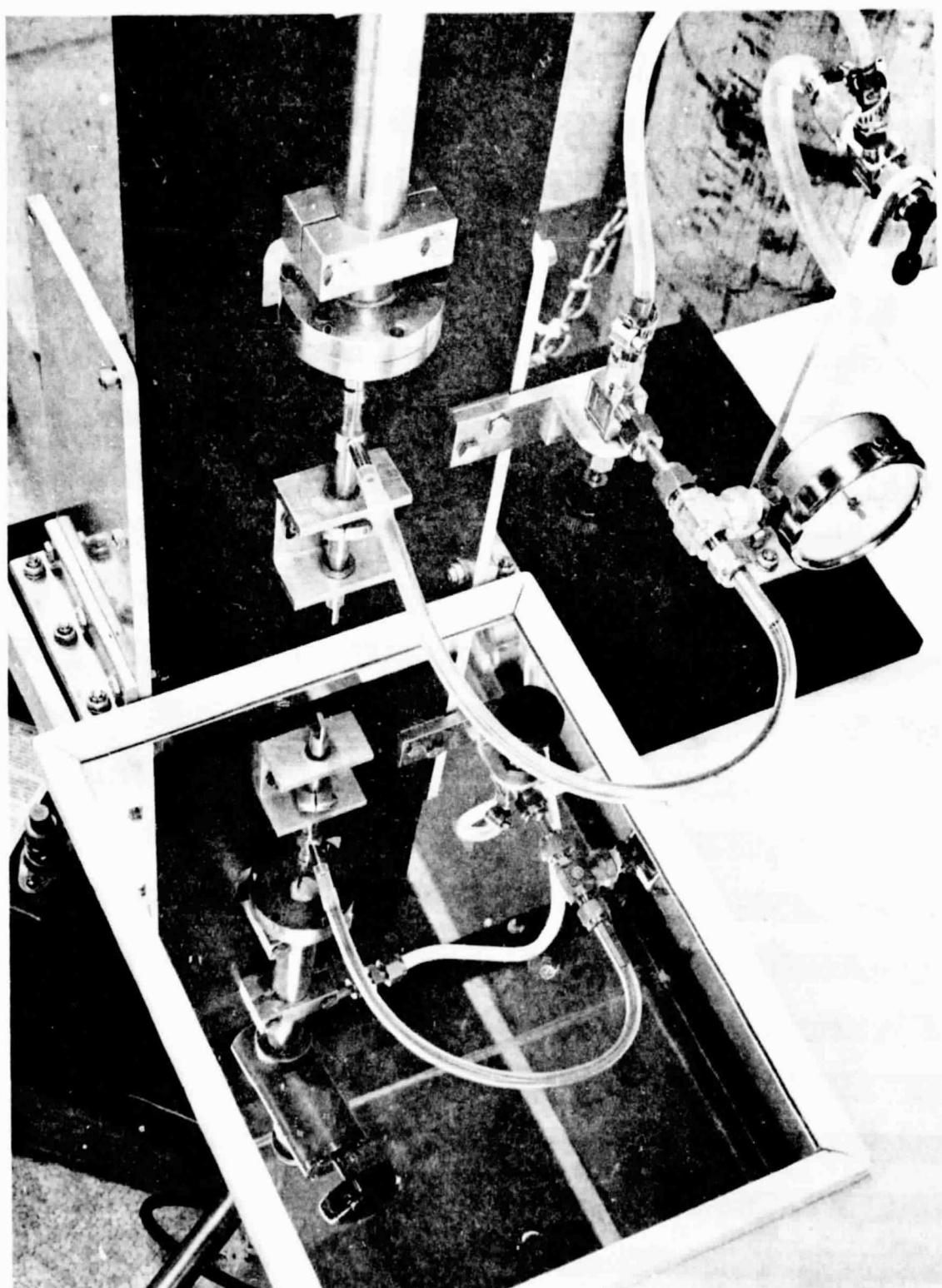


Figure 5. Septum Water Out-Leakage Test

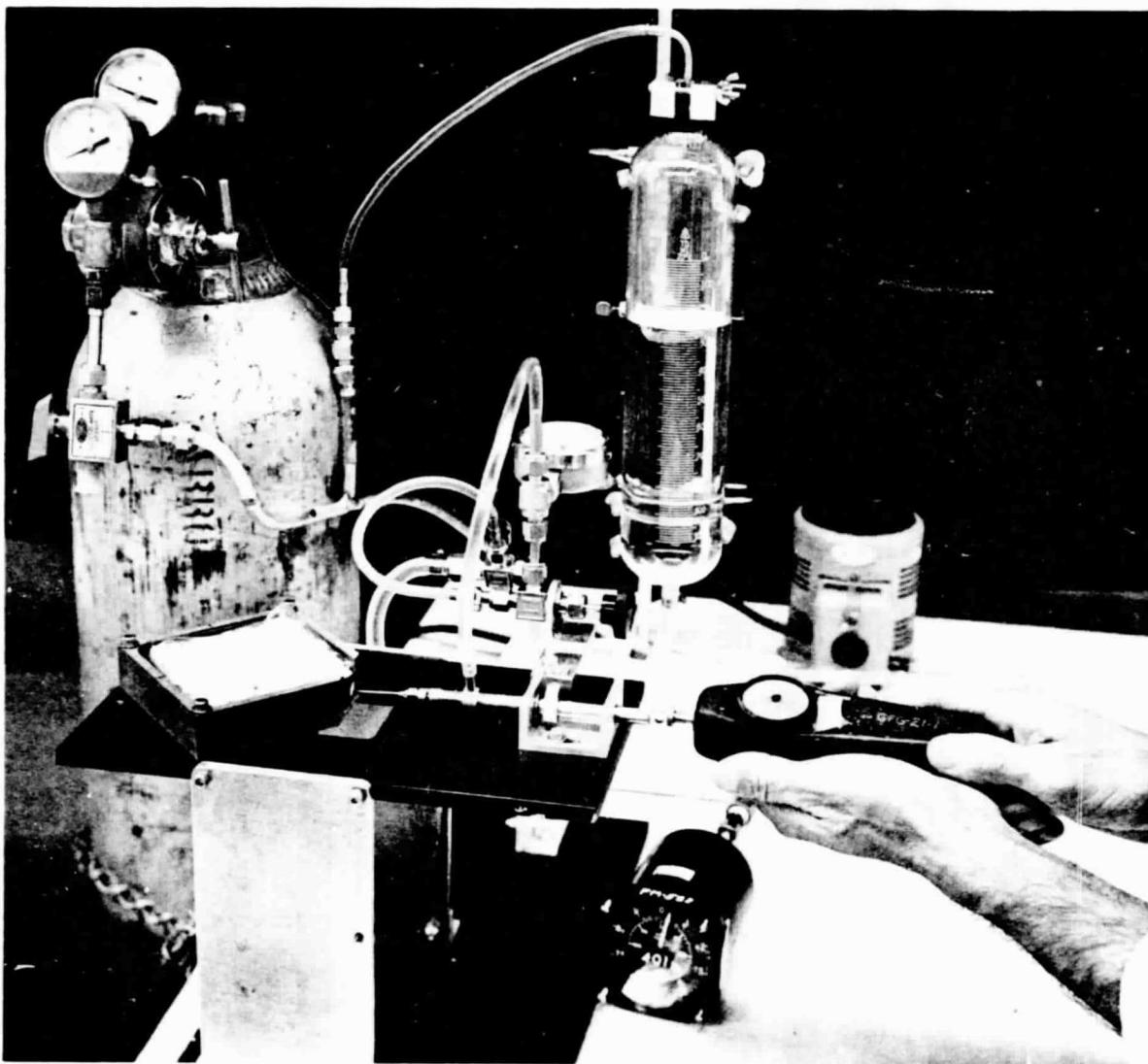


Figure 6. Septum Resistance Test

6.0 TEST RESULTS

6.1 Food Package Characteristics

The food package supplied by the Pillsbury Company consists of a laminated plastic film wrapper in which the food is vacuum sealed. This bag is sealed in a semi-rigid plastic dish to provide support.

6.1.1 Dimensional Variation

The food package is nominally $0.1 \times 0.1 \times 0.025$ m (4 x 4 x 1 inch) with the corners rounded to a 0.02 m (0.75 inch) radius. The package has some flexibility and may be somewhat distorted in fabrication when the evacuated and sealed bag is brought up to pressure. There is also some variation in height depending on food type and quantity, and by the folds of the food wrap.

Fifty-four packages of the following food types were measured:

- Beef and Rice
- Rice and Chicken
- Beans and Franks
- Chili with Beans
- Carrots
- Corn
- Peas
- Cottage Cheese
- Applesauce

The average maximum height of the packages was 0.0257 m (1.01 inch) with a standard deviation of 0.0021 m (0.08 inch). A measure of the package distortion is the difference between the two diagonals of the package. The average difference is 0.0018 m (0.07 inch). In 70 percent of the packages the difference was less than 0.0016 m (0.06 inch) and in only one package was the difference as great as 0.0064 m (0.25 inch). This amount of distortion presents no difficulty in positioning the package in its holder. In every case the septum was well aligned with the needle axis so that penetration is at the center of the septum.

6.1.2 Food Package Internal Air

Most of the food packages have internal air pressures clustered about 3300 N/m^2 (25 mm Hg). Only 10% were in excess of 5300 N/m^2 (40 mm Hg). This low air content

is confirmed when the packages are rehydrated at 1-g by the apparently small air volume rising to the surface.

6.1.3 Septum Thickness Variation

Septum thickness in the food package is somewhat difficult to measure since the food package surface can be highly variable in shape. Probably no septum was less than 0.005 m (3/16 inch) thick. The thickest septum was approximately 0.013 m ($\frac{1}{2}$ inch).

6.2 Septum Leakage

6.2.1 Air In-Leakage

With the 15 gauge needle air in-leakage presents no problem. With one atmosphere differential pressure, the maximum pressure rise in the test chamber was 133 N/m^2 (1 mm Hg) during a 30 second test. The slight leakage occurs during needle penetration. The minimum septum thickness tested was 0.0032 m (1/8 inch).

6.2.2 Water Leakage

6.2.2.1 Food Package

In no food package was there any evidence of water leakage through the septum. Most handling loads do not generate significant pressures at the septum because the flexible package distorts easily when the food is rehydrated. To generate appreciable pressures, the palm of the hand was placed over all of the top surface and pressed harder than in any conceivable normal handling procedure.

There was no water loss during the 20 minute holding time in the oven, as measured by the constant package weight.

6.2.2.2 Septum Specimen

Quantitative data on septum leakage is possible with the apparatus described in Section 5.4.2.1. The tests were conducted primarily with needles (b) and (c) (Figure 1, ref.). The standard needle tip, (a), tended to cut little cores from the septum material. This did not prevent water flow but might build up in time to cause a significant pressure drop.

With a septum thickness greater than 0.006 m (0.25 inch) there was no leakage up to pressures of $41,400 \text{ N/m}^2$ (1 psig). At 0.005 m (3/16 inch) drops of water formed at the septum at pressures of 1-2 psig. To get a flow of at least 1 drop/sec, the pressure would have to be doubled.

The pressure required to cause water leakage depends not only on the septum thickness but also on the restraints that prevent the septum from distorting under pressure. The septum lateral dimensions are a factor. In the food package the semi-rigid dish would act as a restraint. When the septum is allowed to distort the hole formed by the needle opens up. If the septum specimen is reversed in the holder, that is the needle penetrates the film first, then the needle hole tends to seal better under pressure. Thus a 0.0055 m (0.215 inch) septum specimen which leaked at $27,600 \text{ N/m}^2$ (4 psig), showed no leakage when reversed in the holder at pressures up to $82,700 \text{ N/m}^2$ (14 psig).

There is a small difference in sealing ability between the needle shapes. Needle (c), with the axially symmetric point performs better than the wedge shaped point on needle (b). The latter type tends to cut a small slit in the septum and probably produces a larger hole.

6.3 Septum Resistance

The resistance of the food package to the needle insertion is relatively small in all the foods studied and is not particularly dependent on food type except for foods, like fruit, with a high sugar content. The average force required for insertion was 20.9N (4.7 pounds). The lowest was 14.23N (3.2 pounds) and the highest excluding applesauce was 27.6N (6.2 pounds). The applesauce was 37.8N (8.5 pounds). Some fruit like pineapple may not be penetrable at all.

The force required for needle withdrawal is always less than insertion. When the food is wet there no longer is a distinction between the applesauce and the other foods. The average withdrawal force was 10.2N (2.3 pounds) with a range of less than 4.4N (1 pound) to 16.9N (3.8 pound).

The restrained food package distorts slightly as the needle is inserted. The septum is pushed back about 0.0016 m (1/16 inch).

6.4 Water Flow

Water flow rate was measured as a function of the line pressure at the inlet to the needle. A comparison was made between the single axial aperture in needle (a), and the two radial apertures in needles (b) and (c). The needle bore is 0.0014 m (0.054 inch). The needle length up to the aperture is 0.0254 m (1 inch) for needle (a), and 0.0203 m (0.8 inch) for needles (b) and (c).

To achieve a flow rate of 0.454 kg/min (1 pound/min) an inlet pressure of 34,500 N/m² (5 psig) was required for needles (b) and (c). Needle (a) required slightly less pressure 32,400 N/m² (4.7 psig). Some of the food rehydrations were carried out at a flow rate of 0.227 kg/min (0.5 pound/min). At this flow the required inlet pressure was 8,960N (1.3 psig). The presence of food did not appreciably affect the flow rate compared to the bare needle. There will be some back pressure, but the internal vacuum will help the flow. Most of the foods gave a flow rate about 5 percent less than the bare needle. One exception, applesauce, gave a 15% lower rate.

6.5 Package Changes on Rehydration

The introduction of water into the package causes some distention of the film wrapper with a growth in height of the package. The contribution from entrapped air is insignificant. The main factor is free water which is not immediately absorbed into the food mass. The amount of expansion is a function of food type, or perhaps more specifically the quantity of water required for rehydration. Foods such as corn and rice dishes require relatively little water and the percentage change in height is less than 20 percent. Foods such as beans and franks, and chili with beans require more water and the change is about 40%. At the extreme range applesauce almost doubles in height at its highest point. Figure 7 graphs the fractional change in height as a function of the added water quantity.

The free water is absorbed during the holding period and the package shape was generally well preserved by the package dish. To help minimize the initial free water quantity, the water flow rate was cut from the planned 0.454 kg/min (1 pound/min) to one half that rate. A somewhat better absorption resulted.

6.6 Characteristics of Rehydrated Food

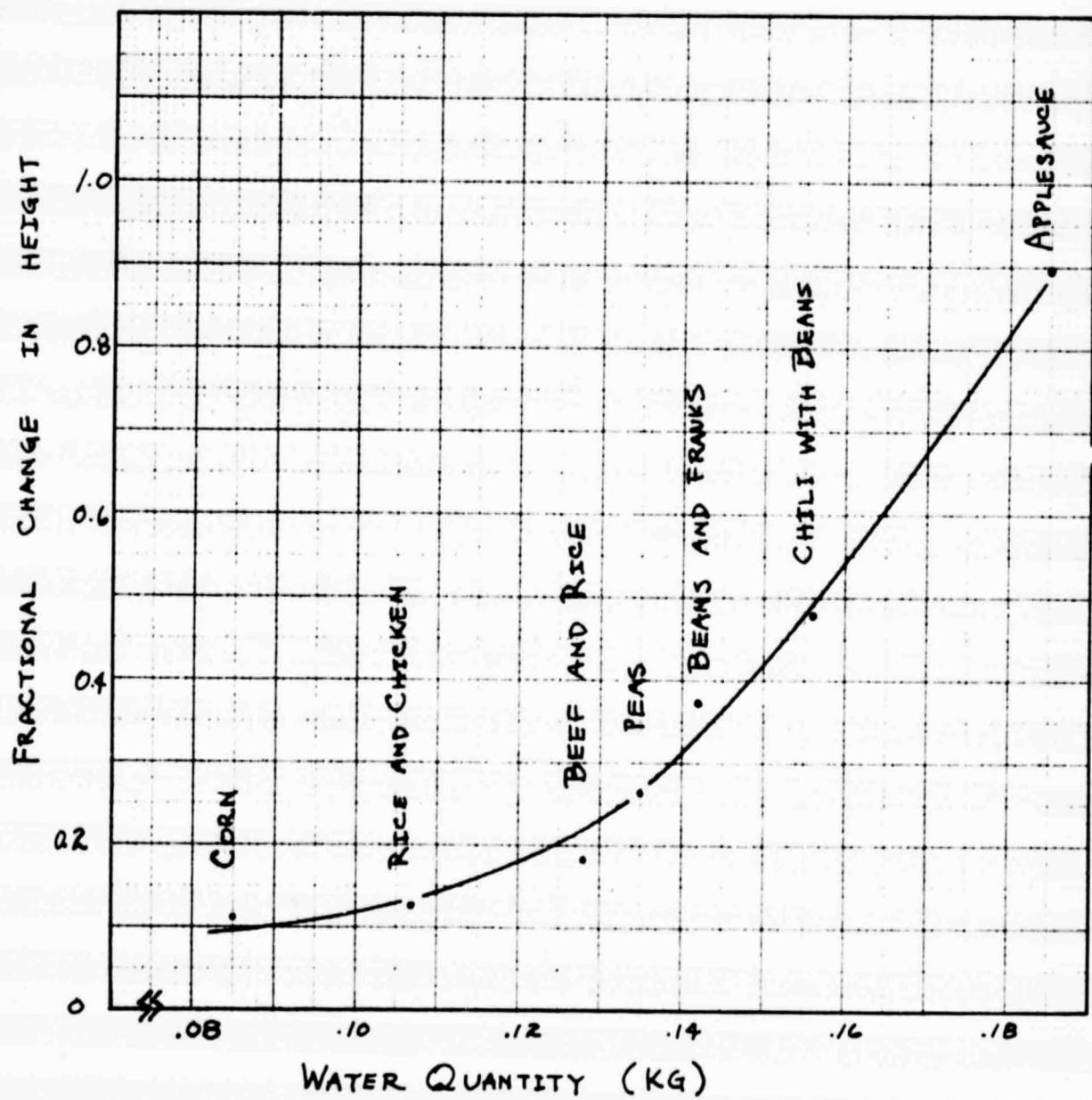


Figure 7. Fractional Change in Package Height as a Function of Quantity of Rehydration Water

6.6.1 Food Temperature

The food package on rehydration with 160°F water was found to be quite easy to handle with bare hands. Transfer from the rehydration device to a food tray insert or oven will not require any handling tools. The temperature of the entrees shortly after rehydration was typically about 135°F. The water to dry weight ratio is as low as 2:1. This is less than the assumed value of 3:1 in preliminary calculations of the required water temperature and results in a temperature lower by about 5°F than expected.

6.6.2 Uniformity of Rehydration

The food mass was generally fairly uniformly rehydrated and there seemed to be very few dry spots. A slight stirring of the food results in a completely acceptable product.

7.0 CONCLUSIONS

The needle probe and septum food package concept has been successfully demonstrated. The package is fairly simply constructed since there are no close tolerances or detailed parts such as valves. The package is easily restrained by an interference fit in the rehydration device and in the food tray. The needle design is inexpensive and can be modified from standard hypodermic needles. The rehydration operation is straight forward and probably leak free. The food packages are manufacturable at a low enough pressure so trapped air does not interfere with rehydration or cause package distortion.

7.1 Needle Requirements

7.1.1 Size

The gauge No. 15 needle is as large as is necessary to achieve acceptable flow characteristics. The Shuttle inlet line to the Galley may be as low as $55,200 \text{ N/m}^2$ (8 psig). Pressure drops in the needle probably should not exceed one half of that. Based on the thickest septum measured, the minimum length of the needle before the apertures should be 0.016 m (5/8 inch). This will allow the apertures to completely clear the septum on insertion. A length of 0.019 m (3/4 inch) will give an adequate safety margin. Any additional length unnecessarily increases the pressure drop.

7.1.2 Shape

Either of the needles (b or c) with radial apertures is satisfactory. The differences in leakage characteristics or ease of penetration is slight. The axial aperture needle (a) is probably not desirable since it does cut cores from the septum material which may build up to foul the needle.

7.1.3 Needle Stroke

The needle stroke on insertion is determined by the clearance necessary to safely insert and remove food packages from the rehydration device, and the depth of penetration required for the needle aperture to clear the septum. This length should be about 0.0254 m (1 inch).

7.2 Package Restraint

The package support should restrain, as a minimum, the two corners adjacent to the corner containing the septum, to minimize package distortion on needle insertion. The insertion forces probably will not exceed 44.5N (10 pounds) so that the holder should be designed to resist at least 178N (40 pounds).

7.3 Needle Actuator Requirements

The forces for insertion are small enough so that little if any mechanical advantage is necessary. The withdrawal forces are less and predictably low. If the needle actuation in zero-g is easier in one direction than the other, than the easier motion should be the insertion.

7.4 Water System

7.4.1 Flow Rate

A flow rate of 0.227 kg/min (0.5 pound/min) may be more desirable than 0.454 kg/min (1 pound/min) since the free water content is somewhat minimized. The impact on time lines for a meal preparation may not be too great since water quantities are small. In addition, pressure drops in the water system are considerably less at the lower rate.

7.4.2 Hot Water Temperature

If a semi-active oven is employed, the hot water temperature should probably be increased from 160°F to 170°F. This will result in a serving temperature which will be more acceptable. If an active oven is employed, the holding time for flavor development and rehydration is sufficient to bring the food temperature to an acceptable level.

7.5 Oven Interface

The oven should provide at least 0.038m (1.5 inch) height clearance for the food package to allow for distortions in the rehydrated package. There is some margin since the weights reported are for the highest point, and the package surface can be somewhat flattened to lower the height.

8.0 RECOMMENDATIONS

The water system should incorporate a needle probe gauge No. 15 with side apertures just beyond the point. The overall length will be slightly greater than 0.0254 m (1 inch) to allow a minimum of .016 m (5/8 inch) of needle length behind the aperture. The water flow could be reduced from 0.454 kg/min (1 pound/min) to one half this value to allow the food mass to take up the rehydration water while minimizing the free water in the package. At this flow a smaller needle could be used without excessive pressure drop. However there is no leakage problem with gauge No. 15 and the insertion forces are modest. The heavier needle should be more resistant to accidental damage. The water temperature of 160°F will be somewhat inadequate for optimum serving temperature unless there is active heating during the holding period for flavor development. The food package holder in the water system and tray can be a simple interference fit with the sides of the package. No special handling tools are required during the hot rehydration. However, the package support in the oven may require some thermal protection at the end of the heating period.

The design of the water rehydration system is so closely related and interdependent on the interface with the food package and septum, it is recommended that the galley designer and the food package designer maintain a continuing interchange of data to assure mutual compatibility.